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(54) [Title] LIGHT SOURCE DEVICE

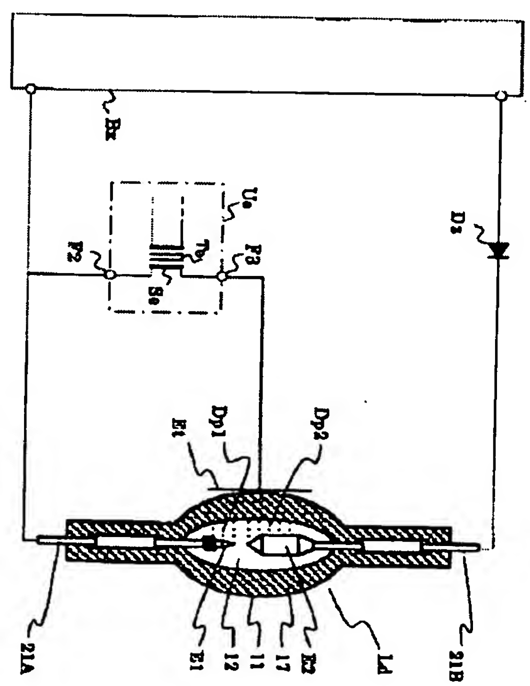
(57) Abstract (Amended)

Problem

To solve the unavoidable problem of a starter being large or heavy in order to avoid heating losses with a coil, to solve the problem that restarting is difficult when only a short time has elapsed since it was turned off and the discharge lamp is hot, and to solve the problem of noise emissions.

Means to solve

In a light source device wherein a pair of main-discharge electrodes E1 and E2 are arranged opposite a discharge space 12, and wherein a discharge lamp Ld provided with an auxiliary electrode Et in addition to the aforementioned main-discharge electrodes so as not to contact main-discharge space 12, a power feed circuit Bx for supplying discharge current to aforementioned main-discharge electrodes E1 and E2, and a starter Ue that generates a high voltage between either of the aforementioned two main-discharge electrodes E1 and E2 and aforementioned auxiliary electrode Et are connected, the light source device is configured so that high voltage is applied to the aforementioned pair of main-discharge electrodes E1 and E2 overlapping during at least some of the period during which the aforementioned starter Ue generates a high voltage.



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Claims

1. In a light source device wherein a pair of main-discharge electrodes (E1, E2) are arranged opposite a discharge space (12), and wherein a discharge lamp (Ld) provided with an auxiliary electrode (Et) in addition to the aforementioned main-discharge electrodes so as not to contact main-discharge space (12), a power feed circuit (Bx) for supplying discharge current to aforementioned main-discharge electrodes (E1, E2), and a starter (Ue) that generates high voltage between one of the aforementioned two main-discharge electrodes (E1, E2) and the aforementioned auxiliary electrode (Et) are connected, a high voltage is applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which the aforementioned starter (Ue) generates a high voltage.

2. Light source device described in Claim 1, characterized in that the value of the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which the aforementioned starter (Ue) generates a high voltage is at least 2.5 times the glow discharge voltage of the aforementioned discharge lamp (Ld).

3. Light source device described in Claim 1, characterized in that the aforementioned discharge lamp (Ld) includes 0.15 mg or more of mercury per 1 square millimeter of the volume of discharge space (12), and the value of the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which the aforementioned starter (Ue) generates a high voltage is at least 500 V.

4. Light source device described in any one of Claims 1-3, characterized in that the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which the aforementioned starter (Ue) generates a high voltage is in the form of pulses.

5. Light source device described in any one of Claims 1-4, characterized in that the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) is produced by one of the electrodes of the aforementioned pair of main-discharge electrodes (E1, E2) to which the aforementioned starter (Ue) is not connected being charged when a discharge is generated in the aforementioned discharge space (12) by the high voltage from the aforementioned starter (Ue).

6. Light source device described in any one of Claims 1-5, characterized in that a high voltage generating section (Ub) that includes at least the high-voltage transformer (Te) of the starter circuit is separated from a power feed circuit section (By).

Detailed explanation of the invention

[0001]

Technical field of the invention

The present invention relates to a light source device that uses a high-pressure mercury discharge lamp and that is used as the light source for a projector, for example.

[0002]

Prior art

In light source devices for optical devices such as liquid crystal projectors or DLP projectors, high-pressure mercury discharge lamps (HID lamps) are used. In recent years, however, there has been a desire to increase the quantity of mercury sealed in the discharge lamp in order to make the aforementioned optical devices brighter. In this type of discharge lamp, a starter must be used to start the generation of a high voltage, and insulation breakdown must be induced in a discharge space to start the discharge.

[0003]

The configuration of a conventional discharge lamp light source device is shown in Figure 19. In optical light sources for optical devices, normally, a starter (Ui) of a type that applies a high voltage between electrodes (E1, E2) at two poles is used. With this type, the secondary winding (Si) of a high-voltage transformer (Ti) in the starter is connected in series to a discharge lamp (Li), so despite the fact that a discharge will start and the function of starter (Ui) is no longer needed, a discharge current must still be supplied to discharge lamp (Li) through secondary winding (Si) of the high-voltage transformer that has a large number of wire turns. In order to suppress heating losses that occur in secondary winding (Si) in this case, the wire diameter in the coil must be made larger, with the problem that the starter (Ui) becoming large and heavy is unavoidable.

[0004]

As a measure to solve this problem, an external trigger system, which is widely used for flash lamp triggers, can be used. With this system, an auxiliary electrode is provided in addition to the two first and second main-discharge electrodes, that is, arc discharge after startup, high voltage is applied between it and the aforementioned first or second electrode, plasma is generated in a discharge space due to dielectric barrier discharge, and the plasma serves as a seed to start the main discharge using the prior applied voltage (no-load open voltage) between the first electrode and the second electrode.

[0005]

By using such a structure, after the start of discharge by the discharge lamp, there is no discharge lamp discharge current to the primary and secondary windings of the high-voltage transformer of the starter, so no heating losses occur at the primary and secondary windings of the high-voltage transformer of the starter, and it is possible to avoid making the starter large and heavy.

[0006]

In discharge lamps in which a large quantity of mercury is sealed, however, when the discharge lamp is cold, the mercury is condensed, so pressure in the discharge space is low, so startup can be performed relatively easily. However, if the time elapsed after turn-off is short and the discharge lamp is hot, then the mercury is vaporized, so pressure in the discharge space is high and there is the problem that restarting (hot start) is difficult.

[0007]

The problem of difficult restarting under hot-start conditions is an important problem in terms of performance that affects the utility for users of a device, for optical devices such as projectors. Because the quantity of sealed mercury has increased in recent years as described above, the problem of difficult restarts has become increasingly more serious for external trigger systems.

[0008]

On the other hand, conventionally a discharge lamp (Li) and a power feed device (Ni) would have been connected with power feed wires (K1, K2), and a starter (Ui) for starting discharge lamp (Li) would have been installed on the power feed circuit side. Starter (Ui) must generate a high voltage. When starter (Ui) generates a pulsed high voltage, there is the problem that power feed wires (K1, K2) discharge high voltages in a short time and intense noises are emitted.

[0009]

In addition, the pulsed high voltage is smoothed due to capacitance between power feed wires (K1, K2) and the peripheral conductors, and the inductance of power feed wires (K1, K2), and an increase in the voltage between electrodes (E1, E2) is lessened, so higher energy than needed must be discharged toward power feed wires (K1, K2) from starter (Ui) in order to obtain the pulsed voltage needed to start the discharge lamp. On top of this, because of the aforementioned smoothing of the pulsed high voltage, the pulse width widens, so the possibility

of insulation breakdown in portions where unintended, such as insulation breakdown in the high-voltage transformer (Ti) of the starter or power feed wires (K1, K2), increases, and there is the risk of this leading to reduced reliability.

[0010]

On the other hand, in the case of a starter that generates a high voltage wherein the voltage rises relatively slowly, called a DC starter, the higher the voltage, and the longer the voltage application time, the more easily the insulation breakdown phenomenon occurs, so there is the problem that the possibility of insulation breakdown occurring in portions where unintended increases even further.

[0011]

Utility Model No. Sho 37[1962]-8045 is a conventional example or design for starting a high-voltage discharge lamp using an external trigger system. In this design, a configuration is described wherein a coil to generate magnetism with the discharge lamp current for the high-pressure mercury lamp is provided, and the operation of a startup circuit that generates a high voltage in an auxiliary electrode using the magnetism is controlled.

[0012]

In addition, the invention in Japanese Kokai Patent Application No. Hei 5[1993]-54983 describes a configuration wherein an auxiliary electrode (external electrode) is disposed at a spacing of several mm from a discharge lamp, such as a high-pressure mercury lamp. In the conventional inventions and designs, however, guidelines or conditions to provide a light source device that can restart while avoiding the problem of insulation breakdown occurring in portions where unintended with the aforementioned hot start have absolutely not been considered.

[0013]

Problems to be solved by the invention

The objective for the present invention is to solve the problems encompassed in the prior art, namely, the problem that the starter must be made large or heavy in order to avoid heating losses by the coils, the problem that restarting is difficult when the time elapsed after shutoff is short and the discharge lamp is hot, the problem of noise emissions, the problem that higher energy than needed must be discharged from the starter to the power feed wires because of capacitive coupling between the power feed wires and peripheral conductors, the problem that the possibility that insulation breakdown will occur in portions where unintended will increase, leading to reduced reliability, etc.

[0014]

Means to solve the problems

In order to solve the problems, the invention in Claim 1 of the present invention is characterized in that, in a light source device wherein a pair of main-discharge electrodes (E1, E2) are arranged opposite a discharge space (12), and wherein a discharge lamp (Ld) provided with an auxiliary electrode (Et) in addition to the aforementioned main-discharge electrodes so as not to contact main-discharge space (12), a power feed circuit (Bx) for supplying discharge current to aforementioned main-discharge electrodes (E1, E2), and a starter (Ue) that generates a high voltage between either of the aforementioned two main-discharge electrodes (E1, E2) and aforementioned auxiliary electrode (Et) are connected, the light source device is characterized in that a high voltage is applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which aforementioned starter (Ue) generates high voltage.

[0015]

The invention in Claim 2 of the present invention is characterized in that, in the invention in Claim 1, the value of the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which aforementioned starter (Ue) generates a high voltage is at least 2.5 times the glow discharge voltage of the aforementioned discharge lamp (Ld).

[0016]

The invention in Claim 3 of the present invention is characterized in that, in the invention in Claim 1, the aforementioned discharge lamp (Ld) includes 0.15 mg or more of mercury per 1 square millimeter of the volume of discharge space (12), and the value of the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which the aforementioned starter (Ue) generates a high voltage is at least 500 V.

[0017]

The invention in Claim 4 of the present invention is characterized in that, in the inventions in Claims 1-3, the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during at least some of the period during which the aforementioned starter (Ue) generates a high voltage is in the form of pulses.

[0018]

The light source device in Claim 5 of the present invention is characterized in that, in the inventions in Claims 1-4, the aforementioned high voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) is produced by one of the electrodes of the aforementioned pair of main-discharge electrodes (E1, E2) to which the aforementioned starter (Ue) is not connected being charged when a discharge is generated in the aforementioned discharge space (12) by the high voltage from the aforementioned starter (Ue).

[0019]

The invention in Claim 6 of the present invention is characterized in that, in the inventions from Claims 1-5, a high voltage generating section (Ub) that includes at least the high-voltage transformer (Te) of the starter circuit is separated from a power feed circuit section (By).

[0020]

Operation

In the case of an external trigger system, in order to start the aforementioned original main discharge, startup ability cannot be increased by just increasing only the high voltage applied between aforementioned first electrode (E1) or second electrode (E2) and auxiliary electrode (Et) or the no-load open voltage. Specifically, the aforementioned high voltage and no-load open voltage must be applied at an appropriate balance according to the time that elapses after shutoff, that is, according to discharge lamp conditions, such as the temperature at the point startup is intended. Even when an appropriate balance is maintained, in actual realization, either or both of the aforementioned high voltage or no-load open voltage to be applied will be very high, and it is obvious that there is the danger of insulation breakdown in portions where not intended as described above

[0021]

Therefore, the shortest elapsed time after shutoff at which restarting is possible is based on the limit of the dielectric strength that can be imparted to the light source device and that is imposed from the standpoints of compactness and economics required by the target optical device.

[0022]

Based on the aforementioned facts, first, the invention in Claim 1 will be explained based on Figures 1 and 2 that relate to experiments conducted by the inventors.

[0023]

Experimental results using a discharge lamp that contains 0.15 mg of mercury per 1 square millimeter of volume of the discharge space and wherein the distance between the aforementioned two first and second main-discharge electrodes is 1.2 mm are shown in Figure 1.

[0024]

The experiment, as shown in Figure 2, was conducted by connecting a DC power source (Mx), a power feed circuit (Bx) and a starter (Ue) to a discharge lamp (Ld). In order to provide voltage independent of the non-load open voltage applied to primary winding (Pe) of the high-voltage transformer of the starter and main-discharge electrodes (E1, E2), here, a variable voltage source (Vp) and a variable voltage source (Va) were connected, and high voltage pulses generated by aforementioned starter (Ue) were applied between first electrode (E1) and auxiliary electrode (Et) while the no-load open voltage was applied to discharge lamp (Ld).

[0025]

The no-load open voltage is applied to discharge lamp (Ld) as the discharge voltage of a capacitor (Ca) through a resistor (Ra) with a high resistance value, and the reason for this is so that current will be supplied quickly from capacitor (Ca) when discharge lamp (Ld) starts up and so that the presence of variable voltage source (Va) will not affect the operation of power feed circuit (Bx) by the resistance value of resistor (Ra) being high after startup of discharge lamp (Ld).

[0026]

Note that the peak voltage (Vtrg) of the high-voltage pulses from aforementioned starter (Ue) is set to 4.4 kV, 8.3 kV, 12.1 kV and 16.1 kV by adjusting variable voltage (Vp), and for the values, the voltage generated at secondary winding (Se) of the high-voltage transformer of aforementioned starter (Ue) was measured using an oscilloscope with secondary winding (Se) of the high-voltage transformer of the aforementioned starter and auxiliary electrode (Et) of the discharge lamp disconnected beforehand.

[0027]

For operating aforementioned starter (Ue), discharge lamp (Ld) was lighted for 4 minutes beforehand, and was operated at an appropriate time interval, using the point of shutoff as the time reference. The time until a successful startup of the discharge lamp (Ld), that is, the disabled time until restart (Trst) was measured (vertical axis in Figure 1).

[0028]

For no-load open voltage (Vopn), 280 V, 350 V, 500 V, 750 V, 1000 V, 1300 V, 1600 V and 1900 V are roughly targeted by adjusting variable voltage source (Va), and the voltage applied to main-discharge electrodes (E1, E2) when startup of discharge lamp (Ld) actually succeeded was measured (horizontal axis in Figure 1).

[0029]

What can be pointed out directly from Figure 1 is the fact that the higher the peak voltage (Vtrg) of the high-voltage pulses from starter (Ue) and the higher no-load open voltage (Vopn), the more the disabled time until restart (Trst) is shortened.

[0030]

Therefore, as stated in the portion for the means for solving the problems for the present invention, the disabled time until restart is shortened, and the problem of restarting under hot-start conditions being difficult is solved by high voltage being applied as non-load open voltage applied to the aforementioned pair of main-discharge electrodes (E1, E2) overlapping during the period during which the aforementioned starter (Ue) generates a high voltage.

[0031]

Next, the inventions in Claims 2 and 3 will be explained. Concerning the fact that the higher the no-load open voltage, the more the disabled time until restart is shortened, in physical terms, requires that high-voltage from starter (Ue) be applied to auxiliary electrode (Et) as described above, a plasma be generated in the discharge space due to dielectric barrier discharge, and that glow discharge, which is the discharge that should be produced first, be generated between main-discharge electrodes (E1, E2) by the no-load open discharge applied using the plasma as a seed. However, this is a stochastic phenomenon that depends on the density of the gas atoms present in the discharge space, and in order to generate glow discharge, the higher the no-load open voltage that is required, the higher the temperature of the discharge lamp. Due to this condition, the glow discharge generating probability rises as the no-load open voltage rises, and can be interpreted as the disabled time until restart being shortened.

[0032]

Looking at Figure 1 even more closely, it can be seen that in the region up to about 500 V, the disabled time until restart will drop abruptly by the no-load open voltage being raised and variation in the disabled time until restart is reduced, independent of peak voltage (Vtrg) of the

high-voltage pulse from starter (Ue). However, when the no-load open voltage is raised above this, the no-load open voltage naturally drops, but the extent of the drop is sharper. In addition, it can be seen that, in the region above about 1600 V, even when the no-load open voltage is increased, the disabled time until restart does not drop much.

[0033]

Therefore, when this discharge lamp is used, in the actual light source device, applying a voltage of at least 500 V, and preferably 600 V or higher, as the no-load open voltage is suitable. In addition, in order not to foster the danger of insulation breakdown in portions where unintended as described above, keeping to no more than 1600 V is beneficial.

[0034]

Even when the generation of glow discharge by the application of high voltage from the starter (Ue) is successful, in order to transition it to arc discharge, it is necessary to inject energy sufficient to achieve continued generation of thermionic emission into the discharge plasma. Because the success rate of the discharge startup by the discharge lamp rises as the no-load open voltage rises, but this energy is different from the glow discharge described above and the dependence on the density of gas atoms present in the discharge space changes, it seems that the tendency for the success rate for discharge startup to rise is concentrated at the aforementioned 500 V voltage.

[0035]

Specifically, the curve represented by the plotted data in Figure 1 can be interpreted to be formed by the overlap of the component whereby the disabled time until restart is shorted as the no-load open voltage rises and the component whereby the disabled time until restart is shortened as the no-load open voltage that is saturated at the aforementioned 500 V voltage rises.

[0036]

In this connection, concerning the component whereby the disabled time until restart is shorted as the no-load open voltage rises in order to transition to the arc discharge described above, there is a relation to how much power must be additionally injected to transition to arc discharge as the success in generating glow discharge, so this phenomenon depends on the glow discharge voltage of the discharge lamp.

[0037]

The typical glow discharge voltage of the discharge lamp used for the experiment in Figure 1 is 180-220 V, so if this is viewed as approximately 200 V, in terms of the connection with 500 V voltage at which the tendency for the disabled time until restart to drop abruptly as described above becomes rare, applying a voltage that is at least 2.5 times the typical glow discharge voltage of the discharge lamp, and preferably a voltage of 3 times or more, is suitable as the no-load open voltage.

[0038]

In addition, in terms of the connection with 1600 V voltage at which the disabled time until restart scarcely drops described above, in order not to foster the danger of insulation breakdown in portions where unintended, this can be reworded that keeping to no more than 8 times the typical glow discharge of the discharge lamp is beneficial.

[0039]

For designing a power feed device for the light source device of the present invention, for the purpose of a test discharge lamp, based on such guidelines, the aforementioned typical glow discharge voltage (Vg) of the test discharge lamp must be discovered experimentally. In this case, though, a DC voltage source for testing is provided having a voltage (Vs) of around 5 times the arc discharge voltage that is, the rated voltage, when the test discharge lamp is lighted steadily. In addition, the rated current, which is the rated power of the test discharge lamp when lighted steadily divided by the aforementioned rated voltage, is calculated, and a current limiting resistor is provided that is roughly equal to the value of the voltage (Vs) of the aforementioned DC voltage source for testing divided by the aforementioned rated current. In contrast to connecting the aforementioned test discharge lamp and the aforementioned current limiting resistor in series, the aforementioned DC voltage source for testing is connected, and the voltage between the main-discharge electrodes, that is, lamp voltage (VL) in the aforementioned test discharge lamp when started up by activating starter (Ue) can be measured by observing with an oscilloscope.

[0040]

A schematic diagram of the waveform of lamp voltage (VL) at startup is shown in Figure 18. In the figure, the starter is activated at time ti, and lamp voltage (VL) exhibits voltage (Vs) of the DC voltage source for testing prior to starter activation, but after starter activation, drops abruptly and exhibits an even voltage only in a short time region (Ag), and then further drops abruptly and describes a transition to an arc discharge region (Aa).

[0041]

Glow discharge is generated in aforementioned time region (Ag), and aforementioned typical glow discharge voltage (Vg) of the test discharge lamp can be found by measuring the voltage at that time. The length of glow discharge time region (Ag) varies according to the lamp structure, the electrode materials, and the composition of the sealed article, and is normally in the range of from several microseconds to several tens of milliseconds.

[0042]

Here, the actual observed waveform of lamp voltage (VL) at startup changes according to discharge lamp state, for example, the lighting time immediately preceding, the time elapsed after shutoff, and how mercury is adhered to the electrodes. Particularly when mercury is adhered to the cathode, arc discharge produced by the presence of the mercury is occurs first, and there are even instances when glow discharge is not clearly observed.

[0043]

For this reason, the test discharge lamp should first be lighted for around 5 minutes to completely vaporize the mercury. Then it is turned off, and with the cathode held to be at the top so that absolutely no mercury adheres to the cathode, is cooled naturally for around 20 minutes, for example, and the aforementioned observation is performed.

[0044]

Note that even when the test discharge lamp is a lamp for AC lighting, observation for a shot time from startup to after the arc discharge transition value at most is performed, so the measuring method for glow discharge voltage described here can also be used.

[0045]

As described above, by configuring the light source device as in the invention in Claim 1, 2 or 3 for the present invention, in addition to restarting characteristics being improved even under the aforementioned hot-start conditions, by using an external trigger system, after the start of discharge of discharge lamp (Ld), there is no flow of discharge current from discharge lamp (Ld) to primary winding (Pe) or secondary winding (Se) of high-voltage transformer (Te) of starter (Ue), so no heating losses occur at primary winding (Pe) or secondary winding (Se) of high-voltage transformer (Te) of starter (Ue), and it is possible to realize a light source device that avoids making starter (Ue) large or heavy.

[0046]

Next, the invention in Claim 4 will be explained. As described above, in order to shorten the disabled time until restart, applying a no-load open voltage at high voltage on the aforementioned pair of main-discharge electrodes (E1, E2) simultaneously with applying the high voltage from aforementioned starter (Ue)) to auxiliary electrode (Et) is effective, but the no-load open voltage at high voltage need not necessarily be DC voltage, or high-voltage AC voltage of long duration in an AC lighting power feed device.

[0047]

Within the no-load open voltage at high voltage that is applied to main-discharge electrodes (E1, E2), the portion in the time region prior to the generation of high voltage by aforementioned starter (Ue) has no significance for shortening the disabled time until restart. Instead, there is the possibility of fostering the danger of insulation breakdown in portions where unintended due to the no-load open voltage being high voltage. For this reason, the level of dielectric strength required overall must be made higher not only for the high-voltage electrical path from aforementioned starter (Ue) to auxiliary electrode (Et) but also for the electrical path from the power feed device to main-discharge electrodes (E1, E2).

[0048]

In this instance, in accordance with the invention in Claim 4, by increasing the no-load open voltage applied to main-discharge electrodes (E1, E2) in pulses, in the electrical path from the power feed device to main-discharge electrodes (E1, E2), the time during which high voltage is applied is shortened, so the danger of insulation breakdown in portions where unintended can be reduced.

[0049]

Note that in this instance, when the high voltage from aforementioned starter (Ue) is DC voltage, the no-load open voltage could be increased in pulses after the start of operation of starter (Ue). In addition, when the high voltage from starter (Ue) is pulsed, operation of the starter and operation to increase the no-load open voltage in pulses must be synchronized so that the period of high voltage from aforementioned starter (Ue) and the period for which pulsed increase in the no-load open voltage is produced will overlap.

[0050]

In this way, by configuring the light source device as in the invention in Claim 4 for the present invention, in addition to restarting characteristics being improved even under the

aforementioned hot-start conditions, it is possible to realize a light source device that avoids making the starter (Ue) large or heavy, and with which the danger of insulation breakdown in portions where unintended is reduced.

[0051]

Next, the invention in Figure 5 will be explained. As shown in Figure 3, when high voltage is applied to auxiliary electrode (Et) of discharge lamp (Ld) from one terminal of secondary winding (Se) of high-voltage transformer (Te) of starter (Ue), a discharge path (Dp1) is formed as a matter of course between the inside surface of the discharge vessel (11) and main-discharge electrode (E1) at the side to which the other terminal of secondary winding (Se) of aforementioned high-voltage transformer (Te) is connected, and dielectric barrier discharge is generated.

[0052]

However, a discharge path (Dp2) is also formed with main-discharge electrode (E2) on the side where the other terminal of secondary winding (Se) of aforementioned high-voltage transformer (Te) is connected, and dielectric barrier discharge is generated. This is because, while a voltage potential of from several hundred V to around 2 kV at most is supplied to the aforementioned two main-discharge electrodes (E1, E2) by power feed circuit (Bx), voltage of from several kV to around several tens of kV is applied to auxiliary electrode (Et), so the potential difference between the aforementioned two main-discharge electrodes (E1, E2) and the inner surface of discharge vessel (11) is sufficiently large.

[0053]

Therefore, a charge is supplied by the dielectric barrier discharge to main-discharge electrode (E2) on the side to which the other terminal of secondary winding (Se) of aforementioned high-voltage transformer (Te) is not connected, so by not allowing the charge to escape, it [electrode] can be charged to high potential. Because of the high-voltage charge, a high-voltage no-load open voltage can be supplied to the aforementioned two main-discharge electrodes (E1, E2).

[0054]

In order that the charge provided by the dielectric barrier discharge not be allowed to escape, most simply this can be achieved by configuring the power feed device so that a diode (Dz) is inserted between power feed circuit (Bx) and main-discharge electrode (E2) on the side

to which secondary winding (Se) of aforementioned high-voltage transformer (Te) is connected, as described in Figure 3.

[0055]

From secondary winding (Se) of aforementioned high-voltage transformer (Te), high-voltage pulses are generated. Basically, only alternating current can be generated at the secondary winding of the transformer, and because of the LC resonating circuit formed by the inductance of the secondary winding (Se) and the capacitance or floating capacitance of aforementioned auxiliary electrode (Et) connected to it, damped oscillation AC high voltage is generated at aforementioned auxiliary electrode (Et).

[0056]

The aforementioned dielectric barrier discharge is generated as each half-cycle, in the phase with positive and negative voltage absolute values in the aforementioned damped oscillation AC high-voltage wave. When aforementioned auxiliary electrode (Et) discharges in a negative phase, main-discharge electrode (E2) on the side to which the other terminal of secondary winding (Se) of aforementioned high-voltage transformer (Te) is not connected will charge negatively, and in this case, forward current will flow to aforementioned diode (Dz), so the charge is neutralized.

[0057]

When aforementioned auxiliary electrode (Et) charges in a positive phase, however, main-discharge electrode (E2) on the side to which the other terminal of secondary winding (Se) of aforementioned high-voltage transformer (Te) is not connected will charge positively. In this case, though, because aforementioned diode (Dz) is inversely connected and there is no current flow, it actually charges positively, and the high voltage generated in this instance will be the no-load open voltage supplied to the aforementioned two main-discharge electrodes (E1, E2) and will continue after charging. Main discharge between the aforementioned two electrodes (E1, E2) can be induced using the dielectric barrier discharge between main-discharge electrode (E1) on the side to which the other terminal of secondary winding (Se) of aforementioned high-voltage transformer (Te) is connected and the inner surface of discharge vessel (11) as a seed.

[0058]

With the invention in Claim 5 in this way, while the configuration for providing high-voltage no-load open voltage to the aforementioned two main-discharge electrodes (E1, E2) is very simple, it is possible to realize a light source device that avoids making the starter large or

heavy, in addition to restarting characteristics being improved even under the aforementioned hot-start conditions.

[0059]

Note that the simplest case was shown in Figure 3, but for actual application, in order to prevent aforementioned diode (Dz) from breaking down when the charge voltage for main-discharge electrode (E2) on the side to which second coil (Se) of aforementioned high-voltage transformer (Te) is connected becomes too high, it is preferable, for example, that a varistor or other protective element whereby the resistance voltage drops when voltage exceeding a prescribed value is applied be inserted in parallel with the aforementioned two main-discharge electrodes (E1, E2), or in parallel with aforementioned diode (Dz).

[0060]

Next, the invention in Claim 6 will be explained. The length of the current path for connecting the secondary circuit section of high-voltage transformer (Te) and aforementioned auxiliary electrode (Et) can be shortened by separating a high-voltage generating section (Ub) that includes at least high-voltage transformer (Te) in the starter circuit from a power feed circuit section (By). Because of this, the capacitance formed between the current path portion for connecting the secondary circuit portion of high-voltage transformer (Te) and aforementioned auxiliary electrode (Et) with peripheral conductors will be smaller, and inductance in the aforementioned current path can be made smaller. For this reason, when the starter is one that generates pulsed high voltage, the adverse effect of voltage between the electrodes is suppressed because of the pulsed high voltage smoothing is reduced due to the presence of capacitance or inductance in the aforementioned current path, and the problem that energy higher than necessary must be discharged is solved. In addition, pulse width broadens due to the aforementioned pulsed high voltage smoothing, and the possibility of insulation breakdown occurring in portions where unintended can be limited. Because the length of the current path for connecting the secondary circuit section of high-voltage transformer (Te) and aforementioned auxiliary electrode (Et) can be made shorter and the loop area can be made smaller, the problem of noise emissions can be limited. In addition, because the length of the connection wire between the aforementioned starter and aforementioned auxiliary electrode (Et) is short, even when the aforementioned starter is one that generates high voltage whereby the voltage rises relatively slowly, the possibility of insulation breakdown occurring in portions where unintended can be limited.

[0061]

In this connection, the insulating capability of the high-voltage transformer (Te) of the aforementioned starter that generates the high voltage inevitably deteriorates as it is used. Also, the discharge lamp (Ld) has a finite lifespan and must be replaced within a limited period of usage. By constructing the aforementioned discharge lamp (Ld) and at least the high-voltage transformer (Te) of the aforementioned starter integrally, when the discharge lamp is replaced because of the end of the discharge lamp's lifespan, the high-voltage transformer (Te) of the aforementioned starter will also be replaced, and the danger of insulation breakdown due to deterioration of the insulating capability of high-voltage transformer (Te) of the aforementioned starter can be prevented before the fact.

[0062]

This is additionally useful for making the length of the connection wire between the aforementioned starter and aforementioned auxiliary electrode (Et) shorter, and the possibility of insulation breakdown occurring in portions where unintended as described above is limited. This is also useful for suppressing the aforementioned problem of noise emissions when the aforementioned starter is one that generates a pulsed high voltage. In this case, simplification of the operate to replace the discharge lamp will be achieved by integrally including an optical means, such as a concave mirror, to direct the light emitted from discharge lamp (Ld) in a specific direction.

[0063]

In this way, by constructing the light source device as in the invention in Claim 6 for the present invention, in addition to restarting characteristics being improved even under the aforementioned hot-start conditions, it is possible to provide a light source device that avoids making the starter (Ue) large or heavy, that greatly lowers the danger of insulation breakdown in portions where unintended, and that reduces the problem of noise emissions.

[0064]

Embodiments

Figure 4 is a simplified embodiment of the invention in Claim 1, 2 or 3. A PFC or other DC power source (Mx) is connected to an inverting chopper type power feed circuit (Br). In power feed circuit (Br), current from DC power source (Mx) is supplied to a choke coil (Lr) by an FET or other switch element (Qr) being turned on, and a smoothing capacitor (Cr) is charged through a diode (Dr) by the dielectric effect of choke coil (Lr) when the switch element (Qr) is turned off.

[0065]

Here, the output of power feed circuit (Br) is characterized in that the absolute value of the voltage can be lowered and raised more than the voltage of DC power source (Mx), which is the input to power feed circuit (Br), due to the output terminal (T2') being a negative value, when output terminal (T1') is the reference, and the duty cycle ratio of switch element (Qr) being adjusted as appropriate.

[0066]

Specifically, a gate signal that has an appropriate duty cycle ratio is applied to switch element (Qr) from a gate drive circuit (Gr) so that the discharge current flowing between main-discharge electrodes (E1, E2) of discharge lamp (Ld), or the voltage between main-discharge electrodes (E1, E2), or the lamp power, which is the product of the current and voltage, will be an appropriate value according to the state of discharge lamp (Ld) at that point. In this instance, the output voltage is not limited to no more than the voltage of the input DC power source, as in the case of a step-down chopper.

[0067]

Normally, a voltage-dividing resistor or shunt resistor for detecting the voltage of smoothing capacitor (Cr) and the current supplied to discharge lamp (Ld) from smoothing capacitor (Cr) is provided in order to control the aforementioned lamp current, voltage or power appropriately, and a control circuit is provided so that gate drive circuit (Gr) can generate the appropriate gate signal, but these are omitted in the figure.

[0068]

When discharge lamp (Ld) is lighted, prior to startup, the aforementioned no-load open voltage generated by power feed circuit (Br) is applied to main-discharge electrodes (E1, E2) of discharge lamp (Ld). Concerning the aforementioned no-load open voltage, as described above, the fact that it is set to at least 2.5 times the glow discharge voltage, and preferably 3 times or more, or when aforementioned discharge lamp (Ld) is one that includes 0.15 mg or more of mercury per 1 square millimeter of the volume in discharge space (12), at least 500 V, and preferably 600 V or more, is beneficial in that the disabled time until restart under hot-start conditions can be shortened.

[0069]

High-voltage side input terminal (F1) and low-voltage input terminal (F2) of starter (Ue) are connected in parallel to discharge lamp (Ld), so voltage the same as the voltage applied to discharge lamp (Ld) is also applied to starter (Ue). Capacitor (Ce) is charged through resistor (Re) by starter (Ue) receiving the voltage.

[0070]

The charge voltage of capacitor (Ce) is applied to primary winding (Pe) of high-voltage transformer (Te) by switch element (Qe), such as an SCR thyristor, being made conductive by gate drive circuit (Ge) at the appropriate timing. So voltage that has been boosted according to the structure of high-voltage transformer (Te) is generated at secondary winding (Se) of high-voltage transformer (Te). In this case, the voltage applied to primary winding (Pe) drops abruptly in accordance with discharge of capacitor (Ce), so the voltage generated at secondary winding (Se) also drops abruptly in the same way, so the voltage generated at secondary winding (Se) will be pulsed.

[0071]

One terminal of secondary winding (Se) of high-voltage transformer (Te) is connected to one electrode (E1) (the cathode in this case) of discharge lamp (Ld), and the other terminal of secondary winding (Se) of high-voltage transformer (Te) is connected to auxiliary electrode (Et) provided external to discharge vessel (11) of discharge lamp (Ld). Discharge is generated by dielectric barrier discharge between the inner surface of discharge vessel (11) of discharge lamp (Ld) and one electrode (E1) of discharge lamp (Ld), and between the inner surface of discharge vessel (11) of discharge lamp (Ld) and the other electrode (E2) (the anode in this case) of discharge lamp (Ld) due to the high voltage generated at secondary winding (Se) of high-voltage transformer (Te).

[0072]

Concerning the design of starter (Ue), as is clear from Figure 1 above, in order for the disabled time until restart to be shortened under hot-start conditions, it is beneficial for the peak value of the high voltage generated at secondary winding (Se) of starter (Ue) to be higher, but because the possibility of insulation breakdown also occurring in portions where unintended, it [peak] should be set as high as possible, within a range remaining within the dielectric breakdown limit according to the dielectric strength that can be provided for high-voltage transformer (Te) of starter (Ue), the dielectric strength that can be provided in the machine [sic; electrical] path from one terminal of secondary winding (Se) to auxiliary electrode (Et) of

discharge lamp (Ld), or the surface distance between auxiliary electrode (Et) of discharge lamp (Ld) and external lead rods (21A, 21B) for electrical connection to main-discharge electrodes (E1, E2).

[0073]

Generally, the secondary voltage of a transformer can be estimated approximately by multiplying the primary and secondary winding ratio by the primary voltage, but in the present case, because it is pulsed as described above, the voltage waveform generated at secondary winding (Se) is affected by parasitic capacitance and leaked inductance from high-voltage transformer (Te). For this reason, the number of wire turns for secondary winding (Se) of high-voltage transformer (Te) could be determined by experimentally producing various numbers of wire turns.

[0074]

In Figure 4 above, a case using power feed circuit (Bx) using an inverting chopper was shown, but an additional embodiment is when the no-load open voltage applied to discharge lamp (Ld) is less than the voltage of DC power source (Mx). A power feed circuit (Bx) using a step-down chopper as shown in Figure 5 can be used.

[0075]

In power feed circuit (Bx), the current from DC power source (Mx) is turned on and off by switch element (Qx), such as an FET, and smoothing capacitor (Cx) is charged through a choke coil (Lx). A gate signal having an appropriate duty cycle ratio is applied to switch element (Qx) from gate drive circuit (Gx) so that the discharge current flowing between main-discharge electrodes (E1, E2) of discharge lamp (Ld), the voltage between main-discharge electrodes (E1, E2), or the lamp power, which is the product of the current and voltage, will be an appropriate value according to the state of discharge lamp (Ld) at that time.

[0076]

Normally, a voltage-dividing resistor or shunt resistor for detecting the voltage of smoothing capacitor (Cx) and the current supplied to discharge lamp (Ld) from smoothing capacitor (Cx) is provided in order to control the aforementioned lamp current, voltage or power appropriately, and a control circuit is provided so that gate drive circuit (Gx) can generate the appropriate gate signal, but these are omitted in the figure

[0077]

Note that in the figure, the structure of starter (Ue) is drawn upside down in relation to starter (Ue) in Figure 4 above. This is because power feed circuit (Br) in Figure 4 above is an inverting chopper, so using output terminal (T1') as reference, output terminal (T2') will be negative voltage. Because power feed circuit (Bx) in Figure 5 is a step-down chopper, using output terminal (T2) as reference, output terminal (T1) will be positive voltage.

[0078]

In Figures 4 and 5, starter high voltage was shown applied between the cathode side of the discharge lamp and the auxiliary electrode, but it could also be applied between the anode side of the discharge lamp and the auxiliary electrode.

[0079]

Figure 6 is an additional embodiment where the invention in Claim 1, 2 or 3 simplified. A step-up chopper circuit comprising a choke coil (Lu), a switch element (Qu), such as an FET, a gate drive circuit (Gu) for controlling switch element (Qu), a diode (Du) [and] smoothing capacitor (Cu) is added to the power feed device in the figure, in contrast to the one in Figure 5 above.

[0080]

Gate drive circuit (Gu) turns switch element (Qu) on synchronized with an appropriate time width to send current to choke coil (Lu), and magnetic energy is accumulated in choke coil (Lu). Next, when switch element (Qu) goes off, the accumulated magnetic energy is released by the dielectric effect of choke coil (Lu), and because smoothing capacitor (Cu) is charged up by this charge through diode (Du), voltage higher than the output voltage of power feed circuit (Bx) can be applied to main-discharge electrodes (E1, E2) of discharge lamp (Ld) as no-load open voltage.

[0081]

In an ordinary step-up chopper power circuit, the output voltage – the voltage of smoothing capacitor (Cu) in the figure here – is detected using a voltage-dividing resistor or the like, and the duty cycle ratio of gate drive circuit (Gu) is adjusted by a feedback circuit so that the error between the detected voltage and as target value will be small.

[0082]

The present invention can be configured in the same way, of course, but in the step-up chopper circuit in the figure, hardly any current will be output from the step-up chopper circuit, and in addition, starter (Ue) can be activated immediately after step-up chopper circuit operation just by discharge lamp (Ld) being connected before startup. After discharge by discharge lamp (Ld) starts, because it is not necessary to generate the no-load open voltage, the step-up chopper circuit may be completely stopped.

[0083]

Therefore, there is greater simplification than with feedback control of the output voltage, such as in an ordinary stop up chopper power circuit. For example, pulses of a prescribed time width could be generated and stopped a prescribed number of times in a prescribed cycle from gate drive circuit (Gu) and then starter (Ue) could be activated.

[0084]

In this case, it is preferable that protective measures be applied for the output of the step-up chopper, such as adding thyristors or other over-voltage protective elements to both terminals of smoothing capacitor (Cu) in the figure, in order to prevent the charge voltage of smoothing capacitor (Cu) becoming too large and insulation breakdown in portions where unintended, or damage to smoothing capacitor (Cu) or diode (Du) occurring due to the step-up chopper circuit being activated to attempt subsequent startup when startup fails and smoothing capacitor (Cu) has not been charged.

[0085]

Figure 7 is an embodiment where the invention in Figure 4 is simplified. This light source device is similar to the one in Figure 6, and differs primarily in that diode (Du) is omitted. For this reason, not only is DC high no-load open voltage applied to discharge lamp (Ld) as in the case of a step-up chopper circuit, a pulsed high no-load open voltage generated by the dielectric effect of choke coil (Lu) is applied immediately after switch element (Qu) turns off.

[0086]

Here, when starter (Ue) is one that generates pulsed high voltage, there must be overlap between at least a part of the synchronization of high voltage generation by aforementioned starter (Ue) and the synchronization of high voltage generation by choke coil (Lu), such as synchronizing the timing at which choke coil (Lu) generates high voltage.

[0087]

An example of a gate drive circuit (Ge) for starter (Ue) and a circuit for generating signals (Sg1, Sg2) to gate drive circuit (Gu), in order for high voltage to be generated in synchronization by starter (Ue) and choke coil (Lu), is shown in Figure 8. At time t0 shown in Figure 9 [showing] a diagram explaining the operation of the circuits, when a start signal (Sm0) is input to a first monostable multivibrator (Fm1), the falling edge thereof is detected, and a high level pulsed signal (Sm1) having a prescribed time width ($\tau 1$) is generated, in accordance with a time constant determined by resistor (Rm1) and capacitor (Cm1). This state is shown in Figures 9 a and b. Generated pulsed signal (Sm1) is input to a second monostable multivibrator (Fm2), and also turns transistor (Qm1) on through resistor (Rm3), activates gate drive circuit (Gu), and turns switch element (Qu) on.

[0088]

At time t1, when pulsed signal (Sm1) returns to low level, second monostable multivibrator (Fm2) detects the falling edge of pulsed signal (Sm1), and a high level pulsed signal (Sm2) having a prescribed time width is generated in accordance with a time constant determined by resistor (Rm2) and capacitor (Cm2). This state is shown in Figure 9 c. Generated pulsed signal (Sm2) turns transistor (Qm2) on through resistor (Rm4), activates gate control circuit (Ge), and turns switch element (Qe) on.

[0089]

During the period when pulsed signal (Sm1) is at high level, switch inhibition [sic; element] (Qu) is on and magnetic energy is accumulated in choke coil (Lu). When pulsed signal (Sm1) returns to low level, choke coil (Lu) released the accumulated magnetic energy and pulsed high no-load open voltage to be applied to main-discharge electrodes (E1, E2) of discharge lamp (Ld) is generated. This state is shown in Figure 9 d.

[0090]

When pulsed signal (Sm1) returns to low level, switch element (Qe) comes on nearly simultaneously, so the charge voltage of capacitor (Ce) is applied to primary winding (Pe) of high-voltage transformer (Te) as described above, and high voltage to be applied to auxiliary electrode (Et) of discharge lamp (Ld) is generated at secondary winding (Se) of high-voltage transformer (Te). This state is shown in Figure 9 e.

[0091]

Note that there is delay at transistors (Qm1, Qm2), but for qualitative considerations here, the explanation ignores the effects of the delay. In addition, the waveforms drawn in Figures 9 d and e show when the discharge lamp is not connected, and therefore when no discharge phenomenon is generated, for the sake of explanation. In this connection, ICs such as SN74HC123 made by Texas Instruments can be used as aforementioned first and second monostable multivibrators (Fm1, Fm2), for example.

[0092]

The light source device in Figure 7 has the advantage that higher efficiency is achieved than the one in Figure 6, since diode (Du) is omitted from the one in Figure 6 so that there are no losses due to the forward voltage in diode (Du) during normal lighting immediately after startup.

[0093]

Figure 10 is an additional embodiment where the invention in Figure 4 is simplified. With this light source device, choke coil (Lu) in Figure 7 above is changed to a secondary winding (So) of a transformer (To).

[0094]

Capacitor (Co) is charged through resistor (Ro). The charge voltage of capacitor (Co) is applied to primary winding (Po) of transformer (To) by switch element (Qo), such as an SCR thyristor, being made conductive by gate control circuit (Go) at an appropriate timing, so voltage that is stepped up according to the structure of transformer (To) is generated at secondary winding (So) of transformer (To), and a pulsed high no-load open voltage to be applied to electrodes (E1, E2) for primary discharge of discharge lamp (Ld) can be realized.

[0095]

Concerning the operating timing of switch element (Qo), and switch element (Qe) in starter (Ue), they are preferably adjusted so that the disabled times until restart is shortened under the aforementioned hot-start conditions, but in actuality, they may often be operated simultaneously. Therefore, there are also cases where the control signal for gate drive circuit (Go) can be one common with the control signal for gate drive circuit (Go) for switch element (Qe), and in those cases, there is the advantage that device structure is simplified.

[0096]

In such cases, aforementioned resistor (Ro), capacitor (Co) and switch element (Qo) are omitted, and by connecting primary winding (Pe) of high-voltage transformer (Te) [of] starter (Ue) and primary winding (Po) of transformer (To) in series or in parallel, the drive circuit for starter (Ue) can also serve to drive transformer (To), and further simplification can be achieved.

[0097]

The light source device in Figure 10 has the advantage that higher efficiency is achieved than the one in Figure 6, since diode (Du) present in the one in Figure 6 is omitted so that there are no losses due to the forward voltage in diode (Du) during normal lighting immediately after startup.

[0098]

Figure 11 is an embodiment where the inventions in Claims 4 and 6 are simplified. In the figure, the starter is configured from a starter transformer drive circuit section (Ua) and a high-voltage generating section (Ub). They are where starter (Ue) described in Figure 4 above is divided, and aforementioned high-voltage generating section (Ub) is installed separated from a power feed circuit section (By).

[0099]

In contrast to wiring from output terminal (F3) of starter (Ue) to auxiliary electrode (Et) described in Figure 4 above transmitting a high-voltage pulse, the connecting wire joining power feed circuit section (By) and aforementioned high-voltage generating section (Ub) and discharge lamp (Ld) is at far lower voltage, so concerns over the adverse effects of extending the connecting wire, that is, that noise emissions or the possibility of insulation breakdown occurring in portions where unintended will increase, are small.

[0100]

Here, ground terminal (F2) of starter (Ue) is divided into ground terminal (F2') of starter transformer drive circuit section (Ua) and ground terminal (F2") of high-voltage generating section (Ub), and power feed to primary winding (Pe) of high-voltage transformer (Te) is accomplished with electrical paths (Kp, Kp') separate from electrical paths (Kv, Kg) to main-discharge electrodes (E1, E2).

[0101]

By so doing, the current at aforementioned primary winding (Pe) of aforementioned high-voltage transformer (Te) flows only through electrical paths (Kp, Kp'), giving a balanced circuit, and noise emissions and malfunctioning are suppressed. In this case, the effect of suppressing noise emissions can be increased further by intertwining (twisting) electrical paths (Kp, Kp'). In addition, noise emissions caused by spike current flowing from aforementioned smoothing capacitor (Cx) to aforementioned discharge lamp (Ld), for example, when main-discharge starts will be suppressed by separately intertwining main-discharge electrical paths (Kv, Kg).

[0102]

Note that in this embodiment, primary winding (Po) of transformer (To) for increasing the no-load open voltage to electrodes (E1, E2) in a pulsed manner, and primary winding (Pe) of high-voltage transformer (Te) of starter (Ue) are connected in series so that both transformers are driven simultaneously from starter transformer drive circuit section (Ua), and simplified circuit configuration is achieved.

[0103]

Figure 12 is an embodiment where the invention in Claim 6 is simplified. In the figure, discharge lamp (Ld) and aforementioned starter high-voltage generating section (Ub) are shown integrated and configured as a lamp unit (Ly). A case where lamp unit (Ly) is configured with a reflecting mirror (Y1) for the output of light emitted from the discharge lamp in a specific direction, a light output window (Y2) that covers the front of reflecting mirror (Y1), and a power feed circuit section (By) integrated with a connector (Cn) for electrically connecting with lamp unit (Ly) is shown.

[0104]

Figure 13 is an embodiment where the inventions in Claims 5 and 6 are simplified. Aforementioned high-voltage generating section (Ub) is installed separated from power feed circuit section (By), the same way as the embodiment in Figure 11. As described above, main-discharge electrode (E2) on the side to which the other terminal of secondary winding (Se) of high-voltage transformer (Te) is not connected is charged with the charge supplied by the dielectric barrier discharge, and a diode (Dz) for supplying a high-voltage no-load open voltage to the aforementioned two main-discharge electrodes (E1, E2) using that high-voltage charge is provided near discharge lamp (Ld).

[0105]

A varistor (Pz) as a protective element is also inserted in parallel with main-discharge electrodes (E1, E2) to prevent aforementioned diode (Dz) from breaking down when the charge voltage of main-discharge electrode (E2) is too high.

[0106]

Figure 14 is an additional embodiment where the invention in Claim 1, 2 or 3 is simplified. The circuitry in this embodiment can apply AC discharge voltage to discharge lamp (Ld') by constructing a full bridge inverter by adding switch elements (Q1, Q2, Q3, Q4), such as FETs, to the circuitry in Figure 5.

[0107]

Switch elements (Q1, Q2, Q3, Q4) are driven by gate drive circuits (G1, G2, G3, G4), respectively, and gate drive circuits (G1, G2, G3, G4) are controlled by a full bridge inverter control circuit (Hc) so that switch elements (Q1, Q4) and (Q2, Q3), which are the full bridge inverter diagonal elements, will conduct simultaneously.

[0108]

Starter (Ue') is the same as starter (Ue) in Figure 5, but one terminal of secondary winding (Si) is connected to ground terminal (F2) with starter (Ue) in Figure 5, and with starter Ue'), is connected directly to the wiring to one electrode (E1') of discharge lamp (Ld') as output terminal (F3').

[0109]

The high voltage generated by output terminals (F3, F3') of starter (Ue') is applied between one main-discharge electrode (E1') of discharge lamp (Ld') and auxiliary electrode (Et), discharge is generated by the dielectric barrier discharge between the one electrode (E1') and the inner surface of discharge vessel (11), and the discharge lamp (Ld') is started.

[0110]

A capacitor (Cv) is provided in parallel with discharge lamp (Ld'), and a coil (Lv) is provided in series in opposition to them. Due to the operating frequency of the aforementioned full bridge inverter being set to a value close to the resonating frequency of the LC resonating circuit formed by aforementioned capacitor (Cv) and coil (Lv), a high AC voltage is generated at aforementioned capacitor (Cv), that is, at discharge lamp (Ld') due to the resonance phenomenon, and a high no-load open voltage is applied between main-discharge electrodes (E1', E2').

[0111]

Note that if the timing at which a high voltage is generated by starter (Ue) has the possibility of timing problems, from the standpoint of the start of discharge by the discharge lamp, when the conductive state of switch elements (Q1, Q2, Q3, Q4) of the full bridge inverter is switched, timing problems, from the standpoint of the start of discharge by the aforementioned discharge lamp can be avoided by the timing at which a high voltage is generated by starter (Ue) being synchronized to be appropriate, or by stopping operation of the full bridge inverter until the start of discharge by the discharge lamp is completed, when switch elements (Q1, Q2, Q3, Q4) are switched.

[0112]

Note that in the embodiments of the present invention, cases where high voltage pulses were generated, such as with starter (Ue) in Figure 4 or Figure 5 above, for example, were primarily described, but a starter (Uf) that generates high voltage whereby voltage rises relatively slowly, called a DC starter, as shown in Figure 15 can also be used.

[0113]

Input terminal (F1) and ground terminal (F2) of starter (Uf) are connected to output terminals (T1', T2') of power feed circuit (Br) or output terminals (T1, T2) of power feed circuit (Bx) the same way as input terminal (F1) and ground terminal (F2) of starter (Ue) in the embodiments such as in Figure 4 or Figure 5 above, and the required voltage is also supplied to starter (Uf).

[0114]

Charging of capacitor (Cf1) through resistor (Rf) is started by starter (Uf) receiving the voltage. Switch element (Qf), such as a sidac, conducts spontaneously when the voltage of capacitor (Cf1) is charged to a prescribed threshold voltage, the voltage is applied to primary winding (Pe) of high-voltage transformer (Tf), and a secondary capacitor (Cf2) is charged through diode (Df) connected to secondary winding (Se). When charging of primary capacitor (Cf1) continues and the current is below a prescribed value, switch element (Qf) spontaneously transitions to non-conducting so that charging of capacitor (Cf1) is again started. The charge in secondary capacitor (Cf2) is summed with each charge and discharge of capacitor (Cf1), and the voltage rises.

[0115]

One terminal of capacitor (Cf2) is connected to one electrode (E1) of discharge lamp (Ld), and the other terminal of capacitor (Cf2) is connected to auxiliary electrode (Et) provided external to discharge vessel (11) of discharge lamp (Ld). When the voltage of capacitor (Cf2) reaches the discharge start voltage at that point, discharge is generated by the dielectric barrier discharge between the one electrode (E1) of discharge lamp (Ld) and the inner surface of discharge vessel (11) of discharge lamp (Ld).

[0116]

If the discharge is generated, the discharge lamp starts, and the transition to arc discharge is successful, the voltage of discharge lamp (Ld), and therefore the voltage supplied to starter (Uf), drops, so the charge voltage of capacitor (Cf1) drops so that switch element (Qf) will not operate.

[0117]

Note that in the embodiments of the present invention, for the starter, cases using ones called a one-stage step-up type, that has one step-up transformer, such as starter (Ue) in Figure 4 or Figure 5 above, for example, were primarily described, but starter (Uk), called a two-stage step-up type as shown in Figure 16, or other ones having two step-up transformers, as well as any other type of means that generates high voltage, can also be applied.

[0118]

Figure 17 is a simplified embodiment relating to the discharge lamp portion of the present invention. In this embodiment, external lead pin (21A) on the cathode side of discharge lamp (Ld) is connected with ground terminal (F2) of starter (Ue) and ground terminal (T2) of power feed circuit (Bx), and external lead pin (21B) on the anode side is connected to positive output terminal (T1) of power feed circuit (Bx).

[0119]

At the same time, auxiliary electrode (Et) comprises a conductor wire (Et1) wound on a portion of cathode side sealed section (13A) near discharge space enclosing section (17) and a conductor wire (Et2) wound on a portion of anode side sealed section (13B) near discharge space enclosing section (17). Aforementioned conductor wire (Et1) and aforementioned conductor wire (Et2) are joined by a conductor wire (W1) and are integrated electrically, and are additionally connected to aforementioned output terminal (F3) of aforementioned starter (Ue) through a conductor wire (We).

[0120]

The advantage of such a structure is that the peripheral length of aforementioned conductor wire (Et1) and aforementioned conductor wire (Et2) is shorter than the peripheral length of the portion of discharge space enclosing section (17) having an enlarged shape, so aforementioned conductor wire (Et1) or aforementioned conductor wire (E52) will not move in a mutually closer direction toward the portion of discharge space enclosing section (17), and because aforementioned conductor wire (Et1) and aforementioned conductor wire (Et2) are joined by aforementioned conductor wire (W1), they will not move in a direction away from each other. Therefore, aforementioned conductor wire (Et1) and aforementioned conductor wire (Et2) can always be kept as installed in their prescribed positions reliably, even when there is repeated thermal expansion and contraction of the various parts caused by the heating cycle of discharge lamp lighting and turning off, or when there is vibration.

[0121]

The reason that such a structure functions satisfactorily as auxiliary electrode (Et) is because aforementioned conductor wire (Et1) and aforementioned conductor wire (Et2) are wound on aforementioned sealed sections (13A, 13B) near aforementioned discharge space enclosing section (17). Thus, the glass in aforementioned discharge space enclosing section (17) in the portions at aforementioned sealed sections (13A, 13B) is strongly polarized by the high voltage of aforementioned starter (Ue), the aforementioned cathode conductor and the aforementioned anode conductor penetrate, that is, contact or are at a very short distance, in the portions of aforementioned discharge space enclosing section (17) in the portions at aforementioned sealed sections (13A, 13B), so a strong dielectric barrier discharge is generated between the portion of aforementioned discharge space enclosing section (17) at the aforementioned cathode side sealed section (13A) and the aforementioned cathode conductor, and between the portion of aforementioned discharge space enclosing section (17) at the aforementioned anode side sealed section (13B) and the aforementioned anode conductor.

[0122]

Therefore, aforementioned conductor wire (W1) that joins aforementioned conductor wire (Et1) and aforementioned conductor wire (Et2) may or may not contact aforementioned discharge space enclosing section (17). Note that the number of wire turns for both aforementioned conductor wire (Et1) and aforementioned conductor wire (Et2) may be 1 turn, or may be 2 or more turns.

[0123]

In Figure 17, in addition to aforementioned conductor wire (Et1), a conductor wire (Et3) is wound surrounding the cathode side sealed section (13A), and aforementioned conductor wire (Et1) and aforementioned conductor wire (Et3) are depicted as forming a coil (CEt) overall.

[0124]

Output terminal (F3) and ground terminal (F2) of starter (Ue) are connected to both terminals of secondary winding (Se) of high-voltage transformer (Te), so during the period when starter (Ue) is not operating, particularly when lighted immediately after the discharge lamp is started, no voltage is generated between output terminal (F3) and ground terminal (F2) of starter (Ue).

[0125]

As described above, cathode side external lead pin (21A) is connected to ground terminal (F2) of starter (Ue), so when lighted, the same potential state is maintained between coil (CEt) surrounding cathode side sealed section (13A) and connection point (Fz) with ground terminal (F2) of starter (Ue) in the wiring from cathode side external lead pin (21A) and ground terminal (T2) of power feed circuit (Bx).

[0126]

In this connection, when discharge lamp (Ld) is lighted, the main-discharge current of discharge lamp (Ld) flows in a path from the tip of cathode (14) through cathode side external lead pin (21A) to connection point (Fz), so a drop in voltage proportional to the product of the resistance value of the path and the value of the current flowing is produced, and the potential becomes higher closer to the tip of cathode (14).

[0127]

As described above, the connection point (Fz) and coil (CEt) are at the same potential, so the potential of the cathode, particularly the portion near sealed section (13A), is higher than that of coil (CEt) enclosing it.

[0128]

For this reason, as described in Japanese Kokoku Patent No. Hei 4[1992]-40828, for the discharge vessel (11) in a discharge lamp that is at a high temperature when lighted, in the portion thereof near sealed section (13), impurity metal cations included in the material of the discharge vessel (11) are driven in a direction away from the electrode material that constitutes

the cathode. The phenomenon whereby the glass material, such as quartz, in the sealed section of the discharge vessel and the aforementioned electrode material separate, due to the impurity metal cations accumulating in the surface of the aforementioned electrode material, is prevented. By configuring the discharge lamp to have the structure described in Figure 17 above, the problem of breakage of the discharge lamp caused by the aforementioned separation phenomenon can be prevented before the fact.

[0129]

Note that the entire portion composed of conductor wires (Et1, Et2, Et3, W1, We) that constitute the aforementioned auxiliary electrode and the aforementioned control can all be configured from one wire by winding on the lamp in this order: connecting conductor wire (We), conductor wire (Et1) on the cathode sealed section (13A) side, conductor wire (W1), and coil (CEt). Here, as the conductor wire material, a material that with high heat resistance, such as tungsten, should be used, since the temperature of discharge vessel (11) and sealed sections (13A, 13B) will be high when the discharge lamp is lighted.

[0130]

Output terminal (F3) and ground terminal (F2) of starter (Uf) are not connected directly to both terminals of secondary winding (Sf) of high-voltage transformer (Tf) as described in Figure 15, and even when a diode (Df) or resistor or other element is inserted in series, there is absolutely no current, or extremely small current, flowing between output terminal (F3) and ground terminal (F2). So even when aforementioned diode (Df) is inserted, there is hardly any drop in voltage (voltage when current flows forward or backward). And even when the aforementioned resistor is inserted, there is hardly any drop in voltage, so an effect whereby the potential of the cathode, particularly the portion near sealed section (13A), will be higher than that of coil (CEt) enclosing it is effectively exhibited.

[0131]

Effects of the invention

With the invention described in Claim 1, 2 or 3, in addition to restarting characteristics being improved, even under hot-start conditions, it is possible to realize a light source device with which the danger of insulation breakdown in portions where unintended is limited, and further, that avoids making the starter large or heavy.

[0132]

With the invention described in Claim 4, in addition to the effects of the invention described in Claim 1, 2 or 3, the possibility of insulation breakdown occurring in portions where unintended can be limited. With the invention described in Claim 5, the invention described in Claim 4 can be realized with an extremely simple configuration. With the invention described in Claim 6, in addition to the effects of the invention described in Claim 1, 2 or 3, the danger of insulation breakdown caused by deterioration of the insulating capability of the high-speed transformer of the starter can be prevented before the fact. In the case of a starter that generates high-voltage pulses, the adverse effects of increased voltages between electrodes due to smoothing of the pulsed high-voltage from the starter and noise emissions are limited. In addition, the possibility of insulation breakdown occurring in portions where unintended is further limited.

Brief description of the figures

Figure 1 are experimental results where the no-load open voltage and the disabled time until restart were measured for different starter voltages.

Figure 2 is the configuration of an experimental circuit for the measurements in Figure 1 and Figure 2 [sic].

Figure 3 is a figure that explains the dielectric barrier discharge produced between the discharge vessel and the two electrodes.

Figure 4 is an embodiment of a light source device for an invention in Claim 1, 2 or 3, using an inverting chopper.

Figure 5 is an embodiment of a light source device for an invention in Claim 1, 2 or 3, using a step-down chopper.

Figure 6 is an embodiment of a light source device for an invention in Claim 1, 2 or 3, using a step-down chopper and a step-up chopper.

Figure 7 is an embodiment of a light source device for the invention in Claim 4.

Figure 8 is an embodiment of a control circuit for the pulse generating circuit in Figure 7.

Figure 9 is a figure showing an example of the various waveforms in the light source device of the present invention in Figures 7 and 8.

Figure 10 is an embodiment of a light source device of the invention in Claim 4.

Figure 11 is an embodiment of a light source device of the invention in Claim 6.

Figure 12 is an embodiment of a lamp unit in a light source device of the invention in Claim 6.

Figure 13 is an embodiment of a light source device of the inventions in Claims 5 and 6.

Figure 14 is an embodiment of an AC lighting type light source device of the invention in Claim 1, 2 or 3.

Figure 15 is an example of a DC starter that can be used for the present invention.

Figure 16 is an example of a two-stage step-up circuit that can be used for the present invention.

Figure 17 is an embodiment of a discharge lamp of the present invention, (a) shows an external view, and (b) shows a part of a cross section.

Figure 18 is a plot of the lamp voltage waveform when a discharge lamp starts.

Figure 19 is a block diagram of a conventional light source device.

Explanation of symbols

11	Discharge vessel
12	Discharge space
13	Sealed section
13A	Sealed section
13B	Sealed section
14	Cathode
17	Discharge space enclosing section
21A	External lead rod
21B	External lead rod
Aa	Arc discharge region
Ag	Time region
Ak	Discharge gap
Br	Power feed circuit
Bx	Power feed circuit
By	Power feed circuit section
CEt	Coil
Ca	Capacitor
Ce	Capacitor
Cf1	Capacitor
Cf2	Capacitor
Ci	Capacitor
Cj	Capacitor
Ck	Capacitor
Cm1	Capacitor
Cm2	Capacitor

Cn	Connector
Co	Capacitor
Cr	Smoothing capacitor
Cu	Smoothing capacitor
Cv	Capacitor
Cx	Smoothing capacitor
Df	Diode
Dj	Diode
Dp1	Discharge path
Dp2	Discharge path
Dr	Diode
Du	Diode
Dz	Diode
E1	Electrode
E1'	Electrode
E2	Electrode
E2'	Electrode
Et	Auxiliary electrode
Et1	Conductor wire
Et2	Conductor wire
Et3	Conductor wire
F1	Input terminal
F2	Ground terminal
F2'	Ground terminal
F2"	Ground terminal
F3	Output terminal
F3'	Output terminal
Fm1	Monostable multivibrator
Fm2	Monostable multivibrator
Fz	Connection point
G1	Gate drive circuit
G2	Gate drive circuit
G3	Gate drive circuit
G4	Gate drive circuit
Ge	Gate drive circuit
Gi	Gate drive circuit

Go	Gate drive circuit
Gr	Gate drive circuit
Gu	Gate drive circuit
Gx	Gate drive circuit
Hc	Full bridge inverter control circuit
K1	Power feed wire
K2	Power feed wire
Kg	Electrical path
Kp	Electrical path
Kp'	Electrical path
Kv	Electrical path
Ld	Discharge lamp
Ld'	Discharge lamp
Li	Discharge lamp
Lr	Choke coil
Lu	Choke coil
Lv	Coil
Lx	Choke coil
Ly	Lamp unit
Mx	DC power source
Ni	Power feed device
Pe	Primary winding
Pf	Primary winding
Pi	Primary winding
Pj	Primary winding
Pk	Primary winding
Po	Primary winding
Pz	Varistor
Q1	Switch element
Q2	Switch element
Q3	Switch element
Q4	Switch element
Qe	Switch element
Qf	Switch element
Qi	Switch element
Qj	Switch element

Qm1	Transistor
Qm2	Transistor
Qo	Switch element
Qr	Switch element
Qu	Switch element
Qx	Switch element
Ra	Resistor
Re	Resistor
Rf	Resistor
Ri	Resistor
Rj	Resistor
Rm1	Resistor
Rm2	Resistor
Rm3	Resistor
Rm4	Resistor
Ro	Resistor
Se	Secondary winding
Sf	Secondary winding
Sg1	Signal
Sg2	Signal
Si	Secondary winding
Sj	Secondary winding
Sk	Secondary winding
Sm0	Start signal
Sm1	Pulsed signal
Sm2	Pulsed signal
So	Secondary winding
T1	Output terminal
T1'	Output terminal
T2	Ground terminal
T2'	Output terminal
Te	High-voltage transformer
Tf	High-voltage transformer
Ti	High-voltage transformer
Tj	Transformer
Tk	High-voltage transformer

To	Transformer
Trst	Disabled time until restart
Ua	Starter transformer drive circuit section
Ub	High-voltage generating section
Ue	Starter
Ue'	Starter
Uf	Starter
Ui	Starter
Uk	Starter
VL	Lamp voltage
Va	Variable voltage source
Vg	Glow discharge voltage
Vopn	No-load open voltage
Vp	Variable voltage source
Vs	Voltage
Vtrg	Peak voltage
W1	Conductor wire
We	Conductor wire
Y1	Reflecting mirror
Y2	Light output window
$\tau 1$	Time width

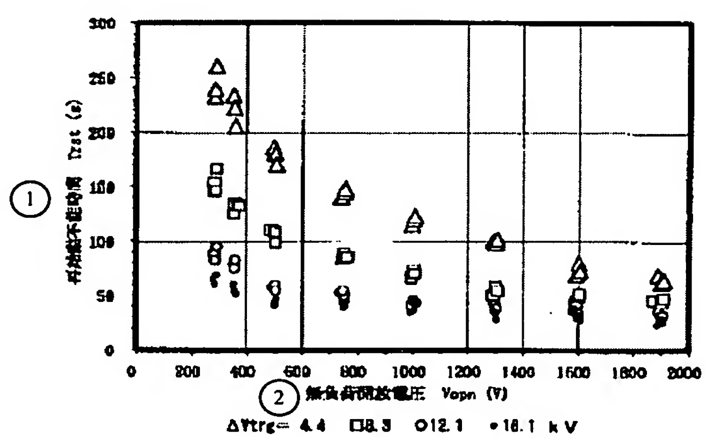
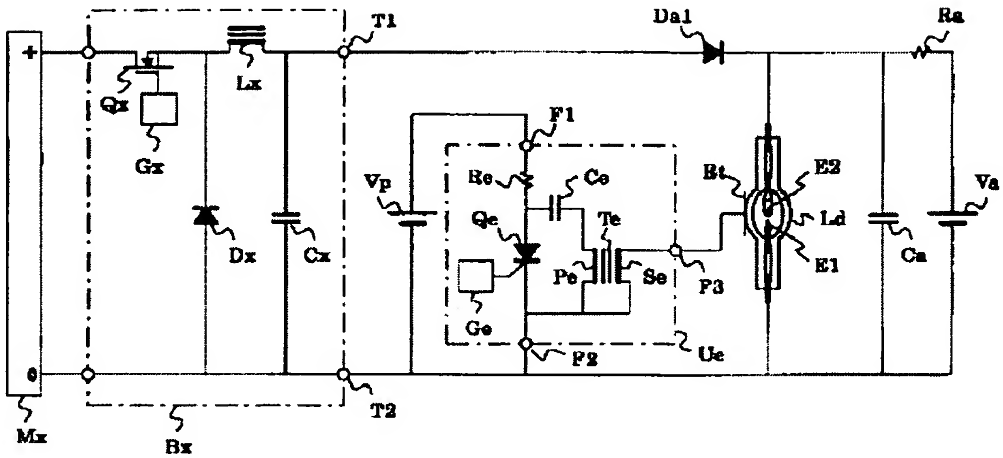


Figure 1

Key: 1 Disabled time until restart Trst (s)
2 No-load open voltage Vopn (V)



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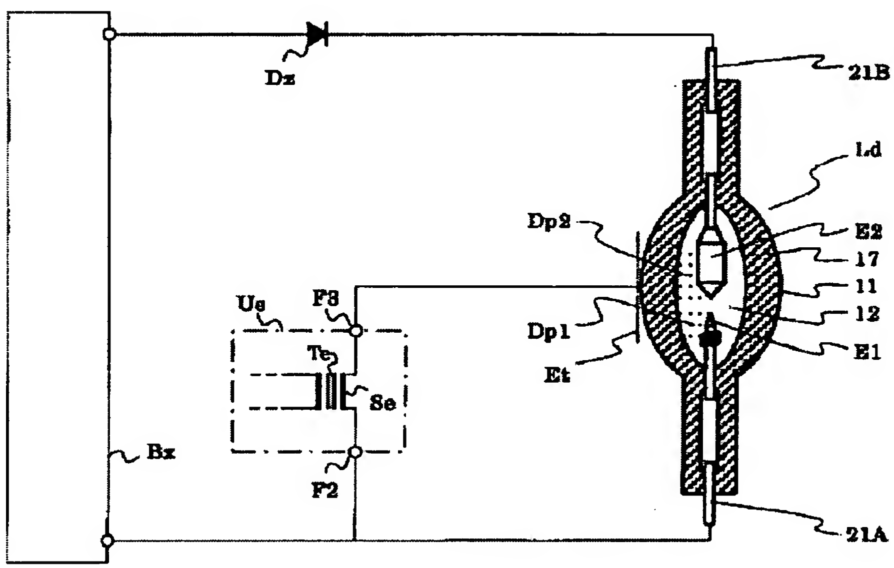

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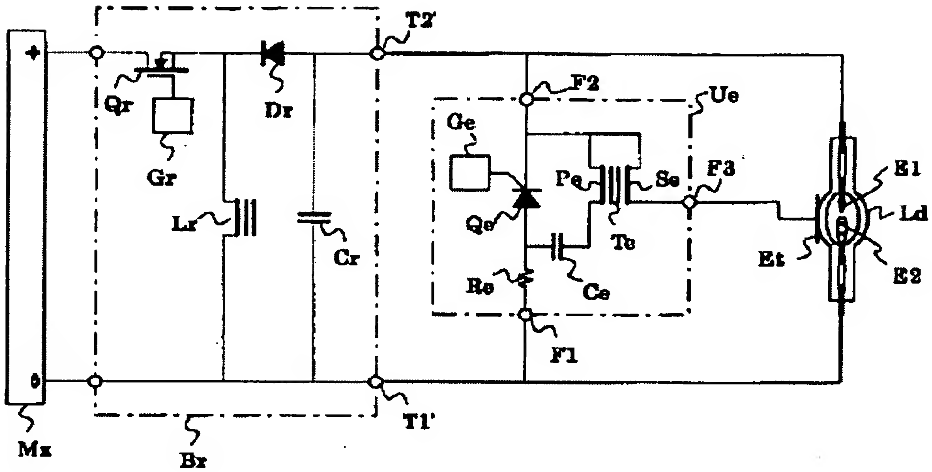
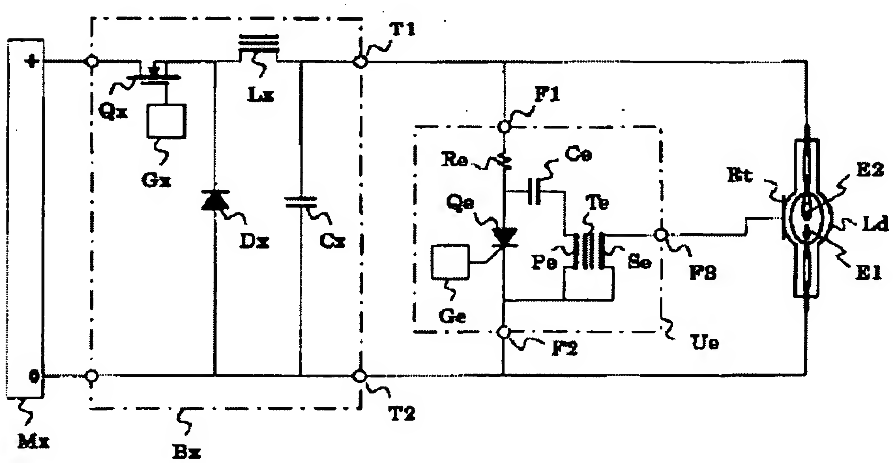


Figure 4



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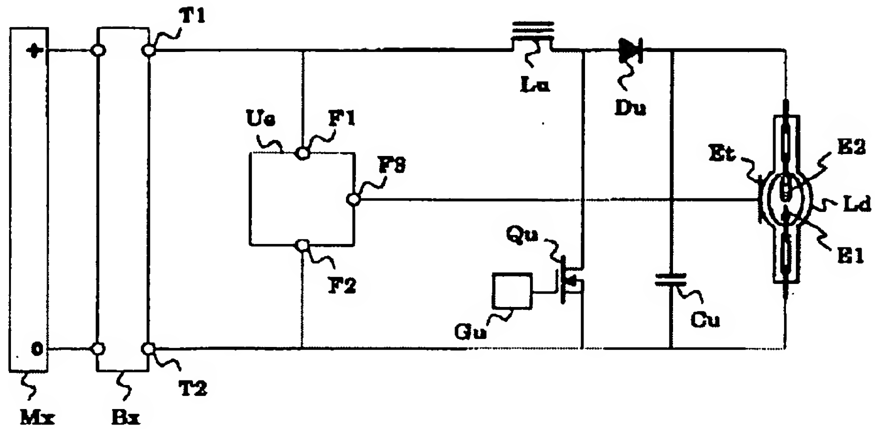

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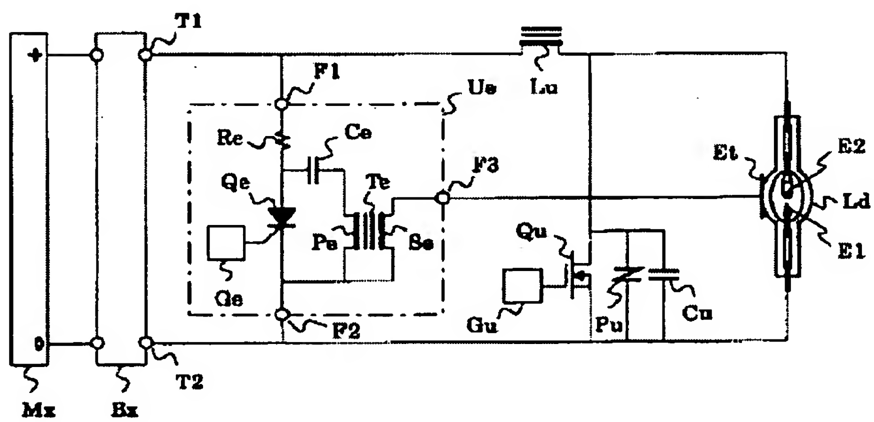

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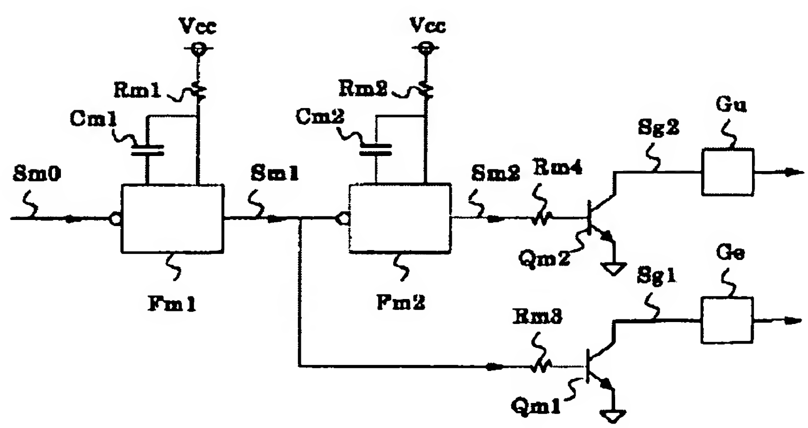
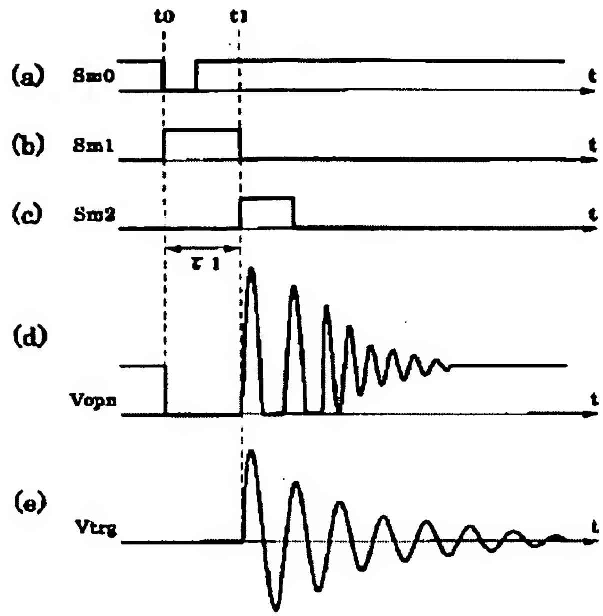


Figure 8



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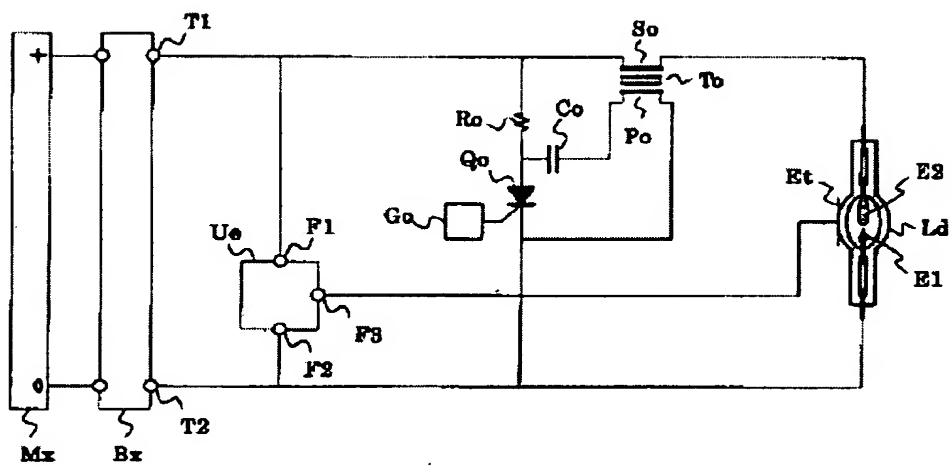

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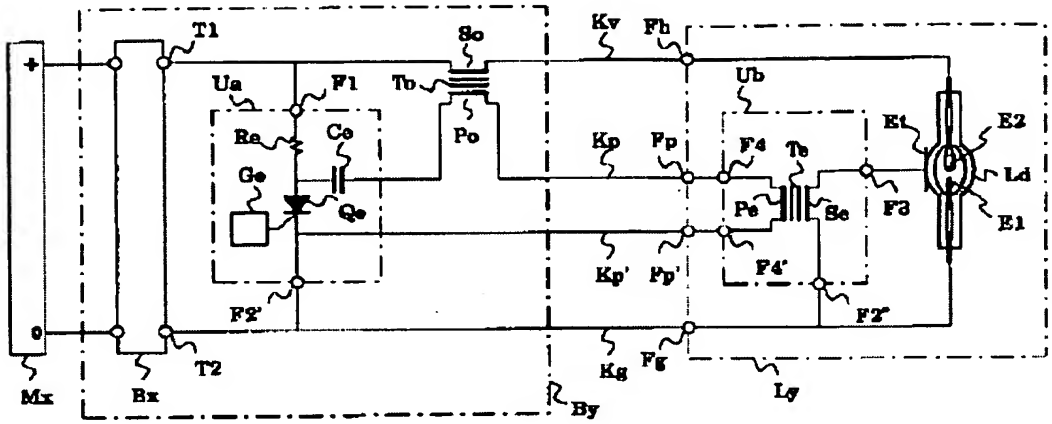

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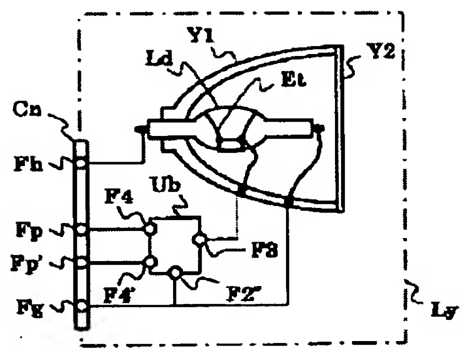

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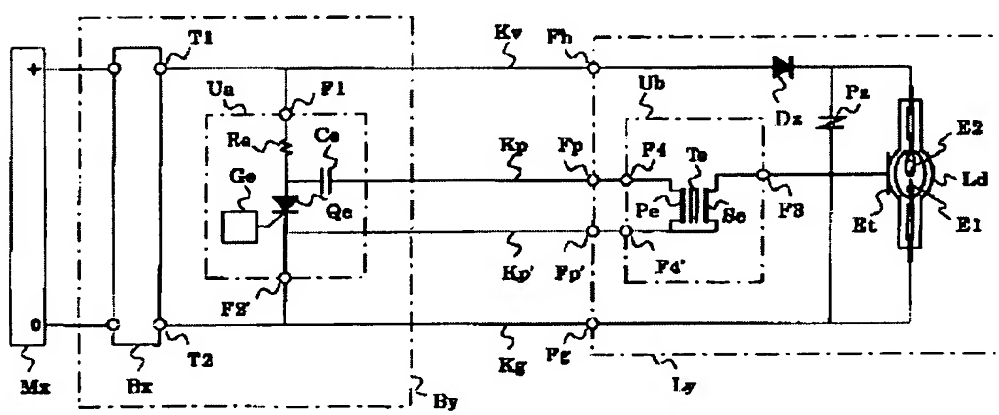

Figure 13

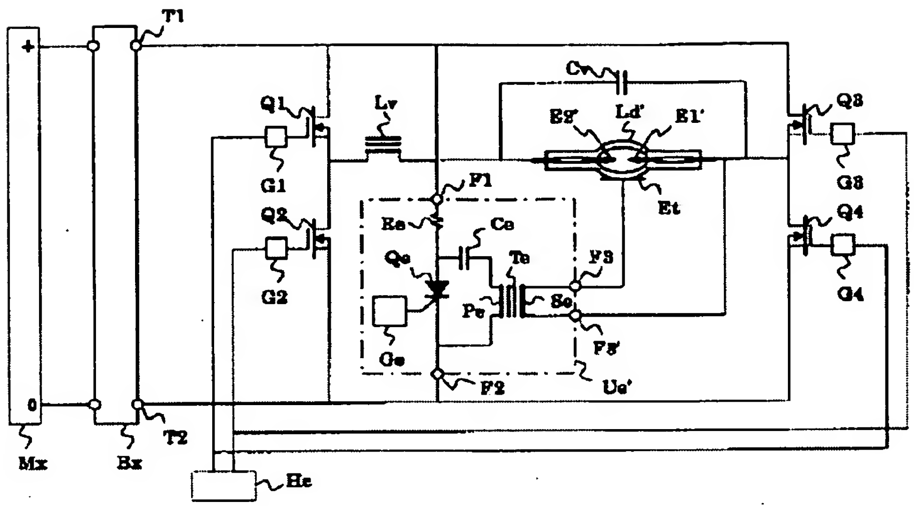

Figure 14

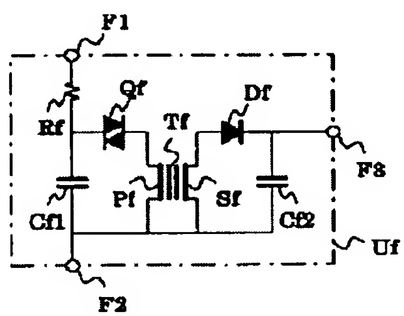

Figure 15

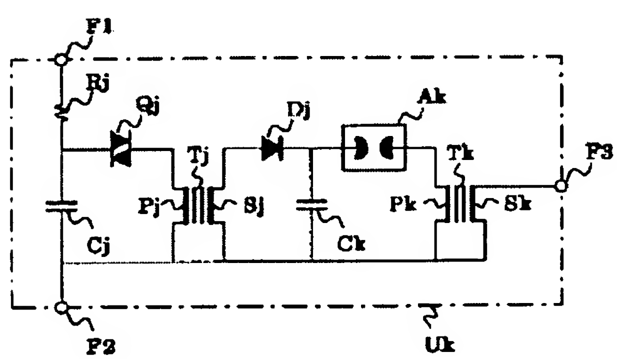

Figure 16

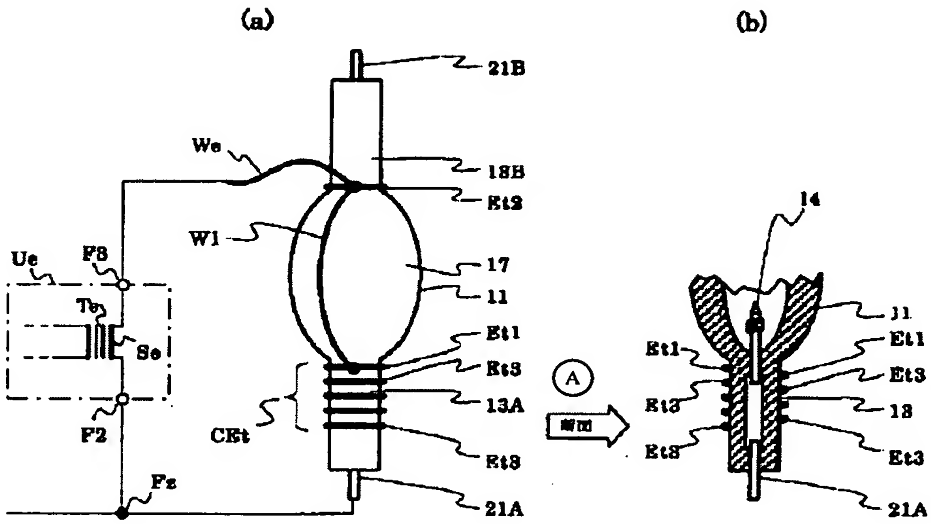

Figure 17

Key: A Cross section

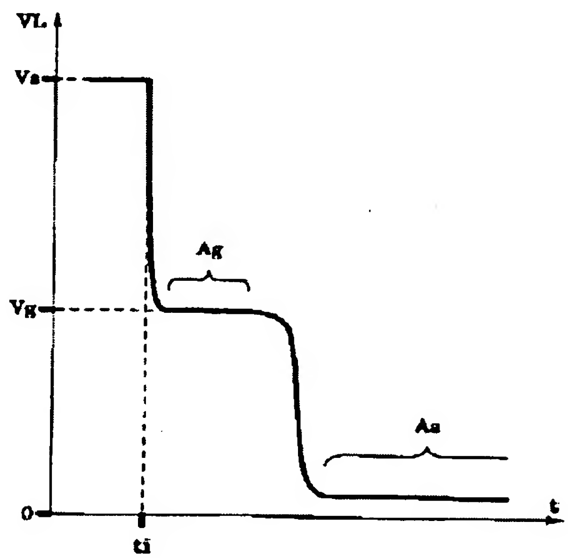

Figure 18

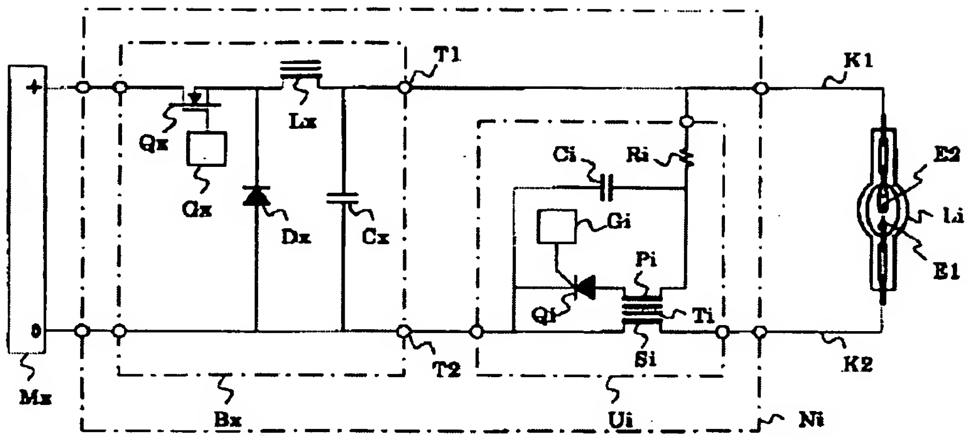

Figure 19

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BC47 BE10 CA09 CA32 EA08
EA09
5C039 BA06